




# Integrating Docker containers in Yocto Project®

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# Presentation

- **Sandra Tobajas**
  - Product engineer at Savoir-faire Linux in Montreal
  - Consultant in embedded systems and product engineering
  - Worked on some BSPs and Linux OSes on various architectures/platforms
  - I like:
    - to work on low level features (bootloader integration, system programming),
    - to parse protocols,
    - to implement or find network security attacks.

# It always starts with a customer's need

- **Worked on different projects with customers**
  - Different business and industrial contexts
    - Healthcare, avionics, manufacturing, entertainment, home automation, etc...
- **But most of them have this question in common**

  *"Hello, I have a (new/old) board and I would like to embed my (rich/legacy) application in a Linux firmware, can you help us ?"*
- **Usage of containers to solve this problem**

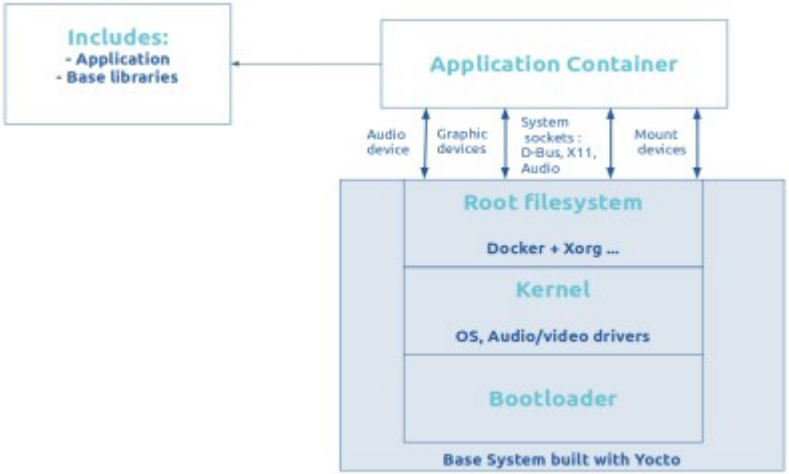
# What is this session about ?

- Why running containers in embedded systems
- Production/Industrialization challenges
- Integrating Docker containers within Yocto

# Why running containers in embedded systems ?

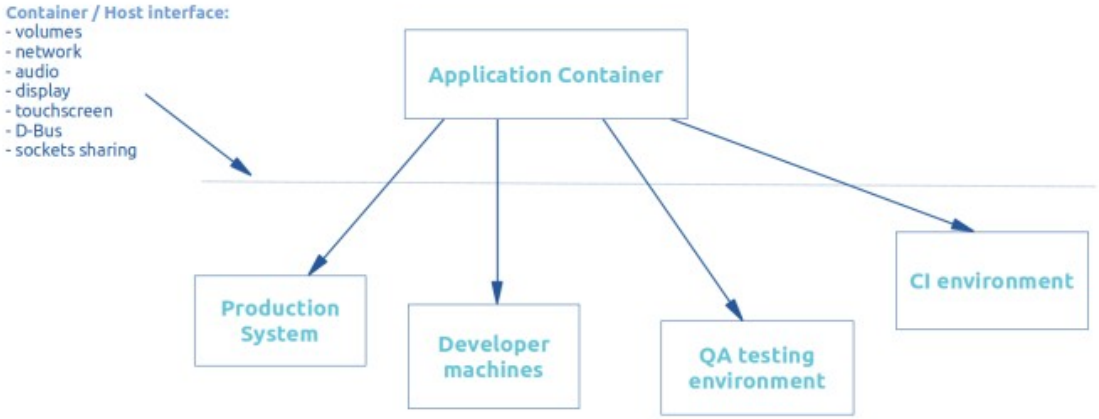
# Why running container in embedded systems ?

- Application independent of the base OS



# Why running container in embedded systems ?

- **Focus on the application development**
  - Platform modularity and application portability
  - Allow asynchronous development cycles



# Why running container in embedded systems ?

- User-space isolation
- Really low overhead vs full/para virtualization
- Platform modularity and portability
- Speed up application development time

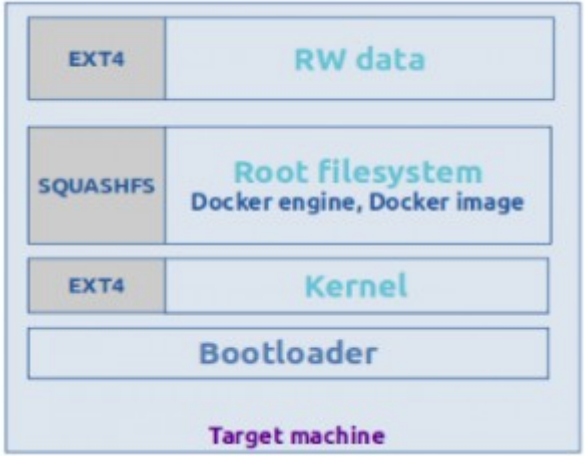
# Production/Industrialization challenges

# Production/Industrialization/Embedded system challenges

- Hardware resource limitations
- System reliability and data integrity
- Cross-platform development
- System provisioning
- System update
- Container traceability and reproducibility
- License compliance

# Production/Industrialization challenges

- **Target requirements**
  - No connectivity on the board
  - Immutable read-only root file system
  - Boot integrity verification
- **Build requirements**
  - Reproducibilty and system provisioning
  - License compliance
  - Yocto build system
  - Containerized build system
    - https://github.com/savoirfairelinux/cqfd
  - Docker images already stored in a registry




Target partition layout

# Production/Industrialization challenges

- **System provisioning**
  - Container integration during build time
  - Container engine installed natively in the build system
  - Docker-in-Docker solution

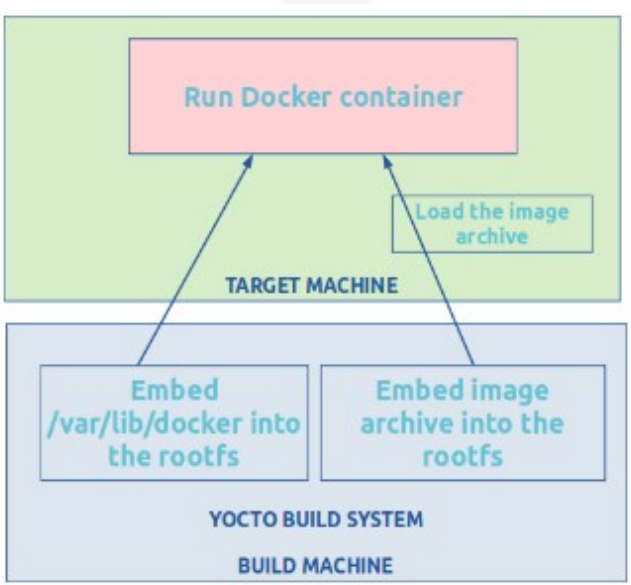
# Production/Industrialization challenges

- **Data corruption**
  - Major cause of embedded device failure
  - Avoid writing operations on rootfs
  - Writable storage options
    - Volatile and non volatile writable filesystem
- **Boot integrity verification**
  - Verifying boot sequence loading
  - Ensure the container image integrity at boot

# Integrating Docker containers within Yocto

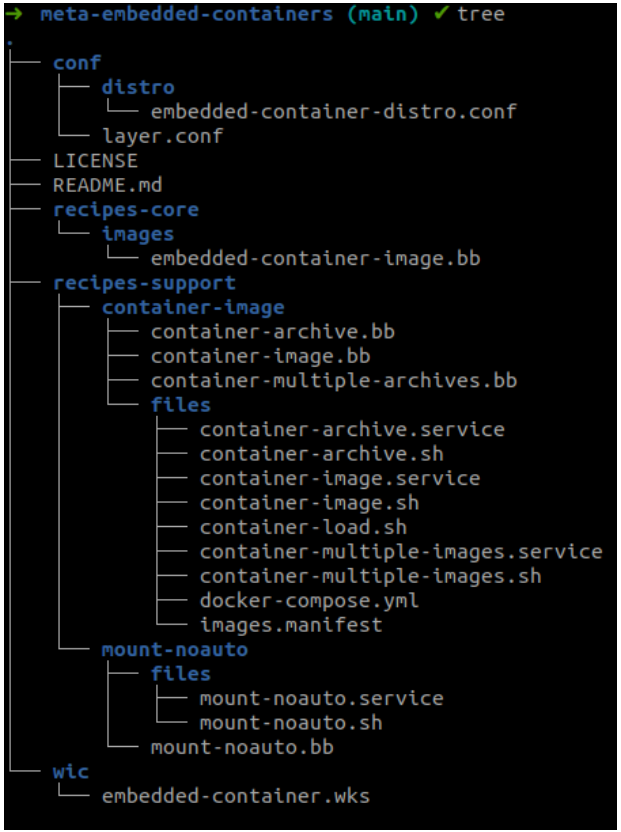
# Integrating Docker containers within Yocto

- **Two approaches**
  - Embed Docker archive in the root filesystem
  - Populate the Docker store into the target root filesystem
- **Docker store = /var/lib/docker directory**



# Integrating Docker containers within Yocto

- Meta-embedded-container tree



# Integrating Docker archive within Yocto

- The distribution file

```
include conf/distro/poky.conf

DISTRO = "embedded-container-distro"

# Append poky based features
DISTRO_FEATURES_append = " virtualization"
DISTRO_FEATURES_append = " systemd"

# Add these binaries to the HOSTTOOLS_NONFATAL variable to allow them to
# be called from within the recipe build task. They are specified as
# NONFATAL as they are not installed at the same time on the build
# system.
HOSTTOOLS_NONFATAL += "sudo pidof dockerd podman newgidmap newuidmap"

# Use systemd as init manager
VIRTUAL-RUNTIME_init_manager = "systemd"
DISTRO_FEATURES_BACKFILL_CONSIDERED += "sysvinit"
VIRTUAL-RUNTIME_initscripts = ""
```

# Integrating Docker archive within Yocto

- The image recipe file

```
require recipes-core/images/core-image-base.bb

DESCRIPTION = "Core image with embedded container images"

IMAGE_FSTYPES += "squashfs"

WKS_FILE = "embedded-container.wks"

IMAGE_FEATURES_append = "\
    debug-tweaks \
    post-install-logging \
    read-only-rootfs \
    ssh-server-dropbear \
    "

IMAGE_INSTALL_append = " \
    container-image \
    docker \
    "
```

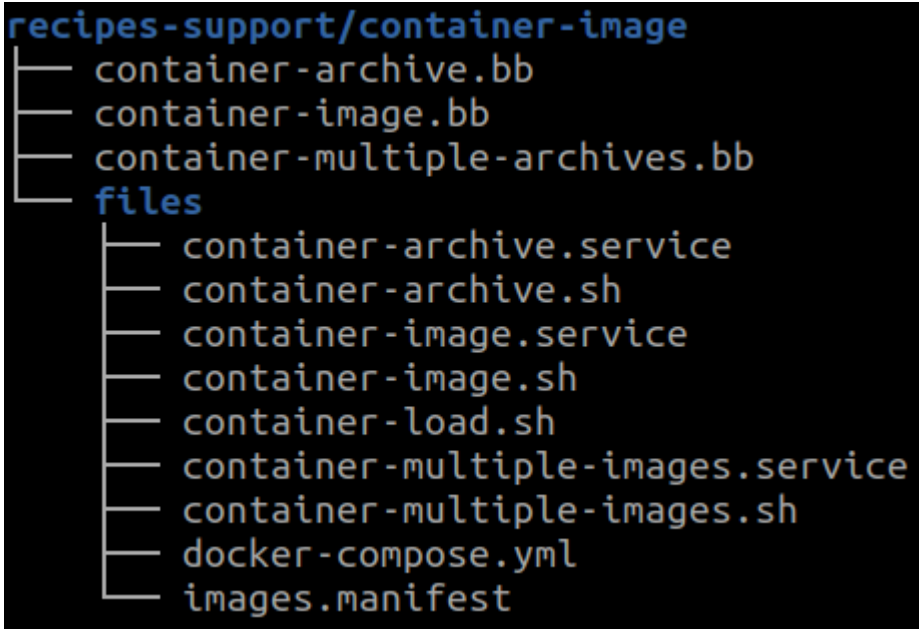
# Integrating Docker archive within Yocto

- The image recipe file

```
update_fstab_archive() {
    install -d "${IMAGE_ROOTFS}/${datadir}/docker-store"

    cat >> "${IMAGE_ROOTFS}${sysconfdir}/fstab" <<EOF

tmpfs       ${datadir}/docker-store  tmpfs defaults 0 0

${datadir}/docker-store /var/lib/docker none noauto,bind 0 2

/tmp/docker-data /etc/docker none noauto,bind 0 2

EOF
}

ROOTFS_POSTPROCESS_COMMAND += "${@bb.utils.contains("IMAGE_INSTALL","container-image", "update_fstab_image;", "", d)}"

ROOTFS_POSTPROCESS_COMMAND += "${@bb.utils.contains("IMAGE_INSTALL","container-archive","update_fstab_archive;", "", d)}"
```

# Integrating Docker archive within Yocto

- Container-image recipe
  - Refactoring as a class



# Integrating Docker archive within Yocto

- Container image manifest
  - The docker registry name
  - The tag
  - Local container name

```
→ meta-embedded-containers (main) ✗ cat recipes-support/container-image/files/images.manifest
busybox 1.32.0 busybox_container
redis 6-alpine redis_container
httpd 2-alpine httpd_container
```

# Integrating Docker archive within Yocto

- Container-archive.bb recipe

```
# The ordre should be:
# 1. do_fetch
# 2. do_pull_image
# 3. do_tag_image
# 4. do_save_image
# 5. do_install
addtask pull_image before do_tag_image after do_fetch
addtask tag_image before do_save_image after do_pull_image
addtask save_image before do_install after do_tag_image
```

# Integrating Docker archive within Yocto

- Container-archive.bb recipe

```
# Pull the container images from the manifest file.
do_pull_image() {

    [ -f "${WORKDIR}/${MANIFEST}" ] || bbfatal "${MANIFEST} does not exist"
    # Specify the PATH env variable allowing Bitbake:
    # - to look for podman binary as /usr/bin is not defined in the originally PATH env
    # variable.
    # - to call /usr/bin/newgidmap and /usr/bin/newuidmap binaries which
    # set uid and gid mapping of a user namespace.
    local name version
    while read -r name version _; do
        if ! PATH=/usr/bin:${PATH} podman pull "${name}:${version}"; then
            bbfatal "Error pulling ${name}:${version}"
        fi
    done < "${WORKDIR}/${MANIFEST}"
}
```

# Integrating Docker archive within Yocto

- Container-archive.bb recipe

```
# Tag the container images with the tag specified in the manifest file.
do_tag_image() {
    [ -f "${WORKDIR}/${MANIFEST}" ] || bbfatal "${MANIFEST} does not exist"
    local name version tag
    while read -r name version tag _; do
        if ! PATH=/usr/bin:${PATH} podman tag "${name}:${version}" "${tag}:${version}"; then
            bbfatal "Error tagging ${name}:${version}"
        fi
    done < "${WORKDIR}/${MANIFEST}"
}
```

# Integrating Docker archive within Yocto

- Container-archive.bb recipe

```
# Save the container images.
do_save_image() {
    local name version archive tag
    mkdir -p "${STORE_DIR}"
    while read -r name version tag _; do
        archive="${tag}-${version}.tar"
        if [ -f "${WORKDIR}/${archive}" ]; then
            bbnote "Removing the archive ${STORE_DIR}/${archive}"
            rm "${WORKDIR}/${archive}"
        fi

        if ! PATH=/usr/bin:${PATH} podman save --storage-driver overlay "${tag}:${version}" \
                -o "${WORKDIR}/${archive}"; then
            bbfatal "Error saving ${tag} container"
        fi
    done < "${WORKDIR}/${MANIFEST}"
}
```

# Integrating Docker archive within Yocto

- Container-archive.bb recipe

```
# Install the manifest inside the root filesystem.
do_install() {
    local name version archive tag
    install -d "${D}${datadir}/container-images"
    install -m 0400 "${WORKDIR}/${MANIFEST}" "${D}${datadir}/container-images/"
    while read -r name version tag _; do
        archive="${tag}-${version}.tar"
        [ -f "${WORKDIR}/${archive}" ] || bbfatal "${archive} does not exist"

        install -m 0400 "${WORKDIR}/${archive}" "${D}${datadir}/container-images/"
    done < "${WORKDIR}/${MANIFEST}"

    install -d "${D}${systemd_unitdir}/system"
    install -m 0644 "${WORKDIR}/container-archive.service" "${D}${systemd_unitdir}/system"
    install -d "${D}${bindir}"
    install -m 0755 "${WORKDIR}/container-image.sh" "${D}${bindir}/container-image"
    install -m 0755 "${WORKDIR}/container-load.sh" "${D}${bindir}/container-load"
}
```

# Integrating Docker archive within Yocto

- **During boot time**
  1) Mount the Docker store in a writable partition.
  2) Execute the Docker daemon.
  3) Load the docker archive file in the Docker store using `docker load` command.
  4) Finally, run the Docker image.

# Integrating Docker archive within Yocto

- **During boot time**
  - /var/lib/docker bind mounted on a tmpfs directory
  - /etc/docker mounted on a tmpfs directory

```
root@genericx86-64:~# findmnt | tail -4
|-/var/lib                          overlay              overlay  rw,relatime,lowerdir=/var/lib,uppe
| `-/var/lib/docker                 overlay              overlay  rw,relatime,lowerdir=/var/lib/dock
|-/var/cache                        overlay              overlay  rw,relatime,lowerdir=/var/cache,up
`-/etc/docker                       tmpfs[/docker-data]  tmpfs    rw,nosuid,nodev
```

# Integrating Docker archive within Yocto

- **During boot time**
  - Container-archive.service

```
[Unit]
Description=Load and start container image at boot
After=mount-noauto.service docker.service
Requires=mount-noauto.service docker.service docker.socket

[Service]
Type=simple
RemainAfterExit=yes
ExecStartPre=/usr/bin/container-load start
ExecStart=/usr/bin/container-image start
ExecStop=/usr/bin/container-image stop
Restart=on-failure

[Install]
WantedBy=multi-user.target
```

# Integrating Docker archive within Yocto

- **During boot time**
  - Container archives present in the rootfs
  - All container images running

```
root@genericx86-64:~# ls /usr/share/container-images/
busybox_container-1.32.0.tar  httpd_container-2-alpine.tar  images.manifest  redis_container-6-alpine.tar
```

```
root@genericx86-64:~# docker ps --all
CONTAINER ID        IMAGE               COMMAND                  CREATED             STATUS                      PORTS               NAMES
1041c59de516        httpd:2-alpine      "httpd-foreground"       16 minutes ago      Up 16 minutes               80/tcp              httpd_container
3b7b5a8017a6        redis:6-alpine      "docker-entrypoint.s…"   16 minutes ago      Up 16 minutes               6379/tcp            redis_container
6c7250fea2f6        busybox:1.32.0      "sh"                     16 minutes ago      Exited (0) 16 minutes ago                       busybox_container
```

# Integrating Docker archive within Yocto

- **With docker-compose**
  - Embedding docker-compose.yml in the rootfs

```
# Install the manifest inside the root filesystem.
do_install() {
    local name version archive tag
    install -d "${D}${datadir}/container-images"
    install -m 0400 "${WORKDIR}/${MANIFEST}" "${D}${datadir}/container-images/"
    install -m 0400 "${WORKDIR}/docker-compose.yml" "${D}${datadir}/container-images/"
    while read -r name version tag _; do
        archive="${tag}-${version}.tar"
        [ -f "${WORKDIR}/${archive}" ] || bbfatal "${archive} does not exist"

        install -m 0400 "${WORKDIR}/${archive}" "${D}${datadir}/container-images/"
    done < "${WORKDIR}/${MANIFEST}"

    install -d "${D}${systemd_unitdir}/system"
    install -m 0644 "${WORKDIR}/container-multiple-images.service" "${D}${systemd_unitdir}/system"
    install -d "${D}${bindir}"
    install -m 0755 "${WORKDIR}/container-multiple-images.sh" "${D}${bindir}/container-multiple-images"
    install -m 0755 "${WORKDIR}/container-load.sh" "${D}${bindir}/container-load"
}
```

# Integrating Docker archive within Yocto

- **With docker-compose**
  - Embedding docker-compose.yml in the rootfs
  - Docker-compose up instead of docker run command

```
version: '3.7'
services:
    myservice:
        image: localhost/busybox_container:latest
    myredisservice:
        image: localhost/redis_container:latest
    myhttpdservice:
        image: localhost/httpd_container:latest
```

```
[Unit]
Description=Load and start multiple container images at boot with docker-compose
After=docker.service mount-noauto.service
Requires=docker.service docker.socket mount-noauto.service

[Service]
Type=simple
RemainAfterExit=yes
ExecStartPre=/usr/bin/container-load start
ExecStart=/usr/bin/container-multiple-images start
ExecStop=/usr/bin/container-multiple-images stop
Restart=on-failure

[Install]
WantedBy=multi-user.target
```

# Integrating Docker store within Yocto

- **Image recipe**
  - /var/lib/docker mounted as an overlayfs to be writable
  - /etc/docker mounted as a tmpfs

```
update_fstab_image() {
    install -d "${IMAGE_ROOTFS}/${datadir}/docker-store"

    cat >> "${IMAGE_ROOTFS}/${sysconfdir}/fstab" <<EOF

tmpfs       ${datadir}/docker-store  tmpfs defaults 0 0

overlay     /var/lib/docker overlay noauto,rw,relatime,lowerdir=/var/lib/docker,upperdir=${datadir}/docker-store/docker,workdir=${datadir}/docker-store/.docker,x-syste
md.requires-mounts-for=${datadir}/docker-store

/tmp/docker-data /etc/docker none noauto,bind 0 2

EOF
}

ROOTFS_POSTPROCESS_COMMAND += "${@bb.utils.contains("IMAGE_INSTALL","container-image", "update_fstab_image;", "", d)}"

ROOTFS_POSTPROCESS_COMMAND += "${@bb.utils.contains("IMAGE_INSTALL","container-archive","update_fstab_archive;", "", d)}"
```

# Integrating Docker store within Yocto

- Container-image.bb recipe
  - Kill Docker daemon
  - Clean Docker store
  - Start Docker daemon
  - Pull Docker images
  - Clean tmp directories
  - Kill Docker daemon

```
do_pull_image() {
    [ -f "${WORKDIR}/${MANIFEST}" ] || bbfatal "${MANIFEST} does not exist"

    [ -n "$(pidof dockerd)" ] && sudo kill "$(pidof dockerd)" && sleep 5

    [ -d "${DOCKER_STORE}" ] && sudo rm -rf "${DOCKER_STORE}"/*

    # Start the dockerd daemon with the driver vfs in order to store the
    # container layers into vfs layers. The default storage is overlay
    # but it will not work on the target system as /var/lib/docker is
    # mounted as an overlay and overlay storage driver is not compatible
    # with overlayfs.
    sudo /usr/bin/dockerd --storage-driver vfs --data-root "${DOCKER_STORE}" &

    # Wait a little before pulling to let the daemon be ready.
    sleep 5

    if ! sudo docker info; then
        bbfatal "Error launching docker daemon"
    fi

    local name version tag
    while read -r name version tag _; do
        if ! sudo docker pull "${name}:${version}"; then
            bbfatal "Error pulling ${name}"
        fi
    done < "${WORKDIR}/${MANIFEST}"

    sudo chown -R "${USER}" "${DOCKER_STORE}"

    # Clean temporary folders in the docker store.
    rm -rf "${DOCKER_STORE}/runtimes"
    rm -rf "${DOCKER_STORE}/tmp"

    # Kill dockerd daemon after use.
    sudo kill "$(pidof dockerd)"
}
```

# Integrating Docker store within Yocto

- Container-image.bb recipe

```
do_install() {
    install -d "${D}${systemd_unitdir}/system"
    install -m 0644 "${WORKDIR}/container-image.service" "${D}${systemd_unitdir}/system/"

    install -d "${D}${bindir}"
    install -m 0755 "${WORKDIR}/container-image.sh" "${D}${bindir}/container-image"

    install -d "${D}${datadir}/container-images"
    install -m 0400 "${WORKDIR}/${MANIFEST}" "${D}${datadir}/container-images/"

    install -d "${D}${localstatedir}/lib/docker"
    cp -R "${DOCKER_STORE}"/* "${D}${localstatedir}/lib/docker/"
}
```

```
do_pull_image[nostamp] = "1"
do_package_qa[noexec] = "1"
INSANE_SKIP_${PN}_append = "already-stripped"
EXCLUDE_FROM_SHLIBS = "1"
```

# Integrating Docker store within Yocto

- **During boot time**
  1) Mount the Docker store as an overlayfs on a writable partition.
  2) Launch the Docker daemon.
  3) Run the container image.

# Integrating Docker store within Yocto

- During boot time

```
[Unit]
Description=Load and start container image at boot
After=mount-noauto.service docker.service
Requires=mount-noauto.service docker.service

[Service]
Type=simple
RemainAfterExit=yes
ExecStart=/usr/bin/container-image start
ExecStop=/usr/bin/container-image stop
Restart=on-failure

[Install]
WantedBy=multi-user.target
```

# Using a container engine in a Docker container

| Container engine | Advantages | Disadvantages |
|---|---|---|
| Podman-in-Docker | - standalone process<br><br>- use of overlay storage driver on large container images<br><br>- rootless | - we had problems running Podman-in-Docker with newer versions than 1.5.1 |
| Docker-in-Docker | - no need to convert the container image | - start the daemon before pulling the image<br><br>- sudo privileges to run the Docker daemon |

# Integrating Docker containers within Yocto

| Solutions | Advantages | Disadvantages | Container engines |
|---|---|---|---|
| Integrating Docker image archive in the root filesystem | - easier to track the pulled image,<br><br>- easier integration in Yocto | - longer boot time | • Podman-in-Docker<br><br>• Docker-in-Docker |
| Integrating Docker store in the root filesystem | - faster boot time,<br><br>- ensure the image integrity included in the root filesystem during boot and runtime,<br><br>- minimize writing operation in the writable partition. | - start the daemon before pulling the image<br><br>- sudo privileges to run the Docker daemon | • Docker-in-Docker |

# Conclusion

- Blog articles on Savoir-faire Linux blog
  - https://blog.savoirfairelinux.com/en-ca/2020/containers-on-linux-embedded-systems/
  - https://blog.savoirfairelinux.com/en-ca/2020/containers-on-linux-embedded-systems/
- Meta-embedded-containers on GitHub (under MIT license)
  - https://github.com/savoirfairelinux/meta-embedded-containers
- Future works:
  - Docker and Podman as native tools ?
  - Container license compliance ?
- Two approaches made from the customer's requirements

# Thanks for your time

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# Me, Myself and I

- **Sébastien LE STUM**
  - Embedded engineer and Director at Savoir-faire Linux
    - Montreal office => Product engineering team
  - Working on solving our customers' problems
    - Embedded products based on Linux
    - Building firmwares using Buildroot / **Yocto** / etc...
    - Design and implement feature-rich userspace applications
  - Cybersec background and Linux enthusiast
    - Past contributions to `tpm2-tools`
    - Developing stuff in Rust (Rust rocks ! :-) )